

Analysis of the binder yield energy test as an indicator of fatigue behaviour of asphalt mixes

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Abstract. Empirical binder testing has increasingly failed to predict pavement performance in South Africa, with fatigue cracking being one of the major forms of premature pavement distress. In response, it has become a national aspiration to incorporate a performance related fatigue test into the binder specifications for South Africa. The Binder Yield Energy Test (BYET) was the first in a series of tests analysed for its potential to predict the fatigue performance of the binder. The test is performed with the dynamic shear rheometer, giving two key parameters, namely, yield energy and shear strain at maximum shear stress ($\gamma_{\tau\max}$). The objective of the investigation was to perform a rudimentary evaluation of the BYET; followed by a more in-depth investigation should the initial BYET results prove promising. The paper discusses the results generated from the BYET under eight different conditions, using six different binders. The results are then correlated with four point bending beam fatigue test results obtained from asphalt mix samples that were manufactured from the same binders. Final results indicate that the BYET is not ideal as an indicator of fatigue performance.

1. Introduction

Bahia *et al* [1] investigated how a simple monotonic shear test, that they named the Binder Yield Energy Test (BYET), gave two parameters, yield energy and shear strain at maximum shear stress ($\gamma_{\tau\max}$), that showed good correlation with the time sweep results published by Martono and Bahia [2]. Good correlation between yield energy and crack length was also found for one project carried out by using an accelerated loading facility (ALF) [1]. The BYET parameters and correlations are illustrated in Figures 1 and 2.

However, other studies have shown poor correlation with cracking [3]. They reported challenges with this test, which include:

- Double-peak behaviour with certain modified binders, which complicate modelling for continuum damage analysis to estimate the fatigue life of the binder,
- Modifiers showing a more pronounced contribution to fatigue resistance at higher strains (i.e. post maximum stress behaviour).

One of the major forms of premature pavement distress in South Africa is fatigue cracking and it was decided to perform a rudimentary evaluation of the BYET as a possible improved indicator of fatigue performance. If the BYET results showed it could potentially serve as an indicator of fatigue



performance, the BYET would be analysed further for incorporation into binder specifications used for asphalt mix design.

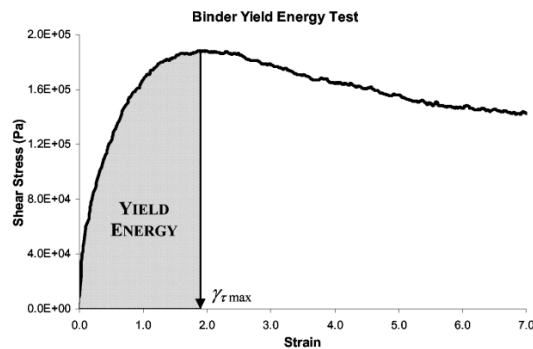


Figure 1. Illustration of the test [1].

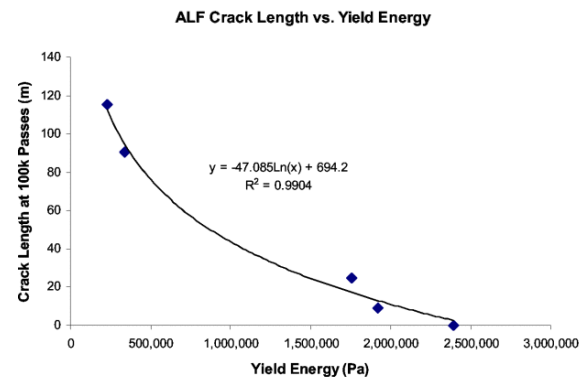


Figure 2. Correlation with ALF data [1].

2. Experimental

2.1. BYET evaluation of six binders

The parameters adopted for the BYET investigation were a combination of the 2009 and 2013 versions of the test method as shown in Table 1. The binders were evaluated after short-term rolling thin film oven test (RTFOT) ageing as opposed to long-term pressure ageing vessel (PAV) ageing, given that the asphalt fatigue specimens had only undergone short-term ageing. The following six binders were evaluated:

- Experimental 50/70 penetration grade binder created in a laboratory.
- 50/70 penetration grade bitumen (produced March 2010)
- 50/70 penetration grade bitumen (produced June 2012)
- EVA-modified binder, locally classified as A-P1 [4]
- Terpolymer-modified binder (Elvaloy), locally classified as A-E1 [4]
- SBS-modified binder, locally classified as A-E2 [4]

Table 1. BYET parameters.

Parameter	2009 Method	2013 Method	Adopted Conditions
Strain Rate (%/s)	1%/s	2.3%/s	1%/s and 2.3%/s
Temperature (°C)	Intermediate Temperature	Any Suitable Temperature	5, 10, 20, 28

2.2. Four point beam fatigue testing of asphalt mixes

The four point beam fatigue test is widely accepted to relate laboratory-derived fatigue life models to observed field performance where bottom-up cracking is the failure criterion [6]. Our methodology included an evaluation of the correlation of the BYET results with the beam fatigue test, which was interpreted as an accelerated representation of fatigue cracking in the field.

The binders that were selected for the BYET were used to manufacture medium continuously-graded hot mix asphalt. It was the goal to keep the asphalt mix properties the same for all the mixes in order that the influence of the binder on the four point beam testing results could be ascertained. When comparing these asphalt mixes, they had:

- Similar gradings (Table 2, Figure 3)
- Binder contents varying between 4.6 and 5.0%
- Void contents compacted to between 6 and 8%

The fatigue testing was conducted using an IPC standalone four-point bending testing setup. The tests were performed according to the CSIR test protocol [5] under controlled-strain loading conditions. The conventional failure criterion defined as the number load cycles to reach 50% reduction in the initial stiffness (N50%) was adopted for testing. A test temperature of 10°C was selected and strain amplitude levels ranged from 200 to 600 microstrain, representing a minimum number of 6 evaluations per mix. Results were plotted on a logarithmic scale for all mixes and the best-fit power graphs were used to calculate the number of repetitions to failure at 300 microstrain, which was the lowest strain amplitude that all the mixes had in common. The calculated value was used for correlation with the BYET results

Table 2. Grading and binder contents of asphalt mixes.

	AE2: SBS	50/70: 2010	50/70: 2012	AP1: EVA	AE1: Elvaloy	Exp. 50/70
Sieve Size	% Passing					
13.2	100	100	100	100	100	100
9.5	95	97	98	91	95	98
6.7	80	75	79	75	80	79
4.75	62	59	64	58	62	64
2.36	40	42	44	43	40	44
1.18	28	30	30	30	28	30
0.6	21	21	20	22	21	20
0.3	16	14	14	15	16	14
0.15	10	9	9	10	10	9
0.075	5.5	5.8	6.6	6.9	5.5	6.6
Binder Content	4.7	5.0	4.7	4.8	4.7	4.7

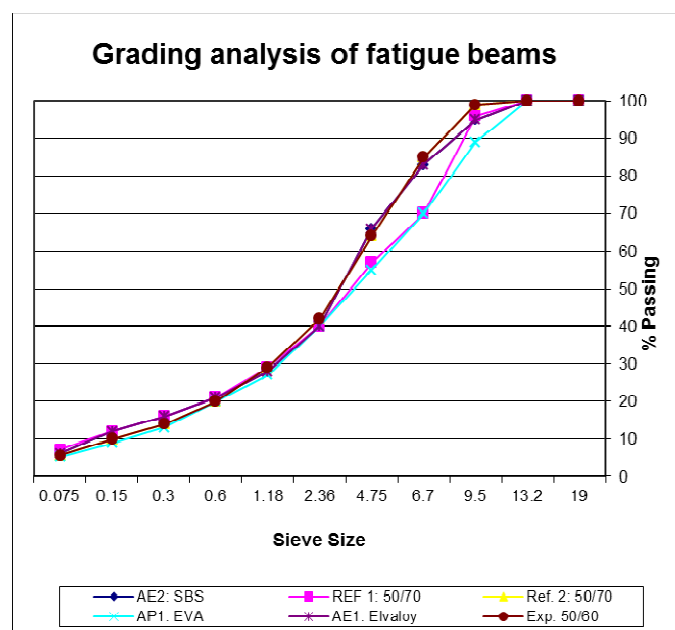


Figure 3. Grading of asphalt mixes.

3. Results

3.1. BYET evaluation of six binders

The repeatability of the BYET was tentatively evaluated by randomly re-testing some of the samples at various temperatures. The results are shown Figure 4. The repeatability was evaluated qualitatively, and a quantitative analysis of the effect of the differences in results was deferred to a later date, should the method prove to have potential.

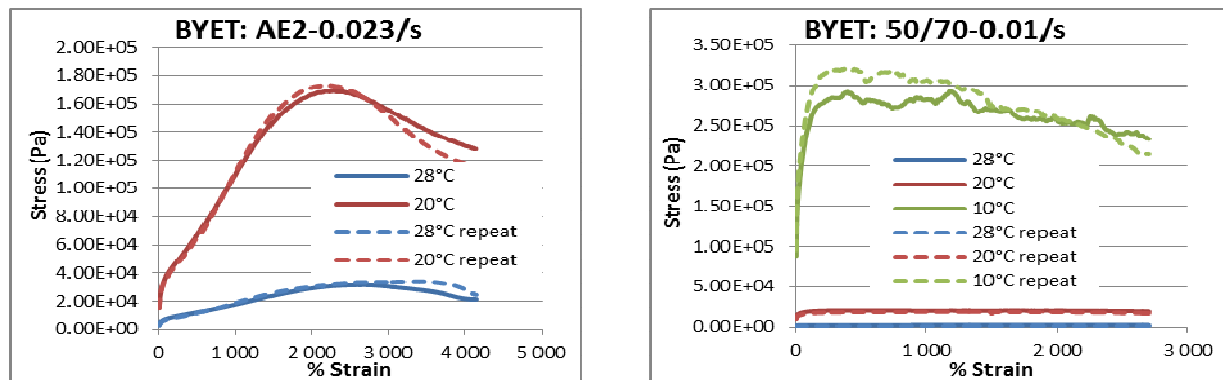


Figure 4. Repeatability of the BYET.

Examples of the BYET results are illustrated in Figures 5 to 7. Each figure shows the results obtained at the four temperatures investigated. In each figure, the test results from the lowest temperatures are removed consecutively as the y-axis is expanded in order to amplify the results obtained for the higher temperatures. Only three examples are illustrated due to space considerations.

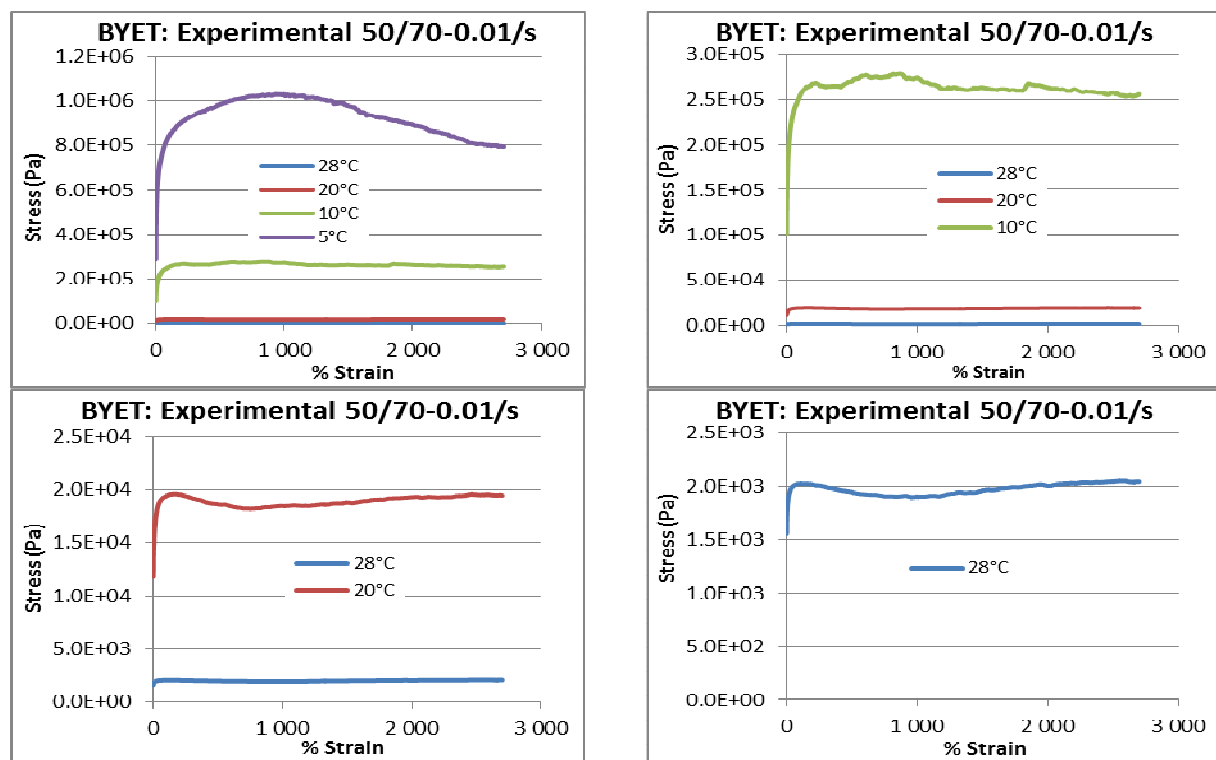


Figure 5. BYET test results for Experimental 50/70 penetration grade binder at 1%/s.

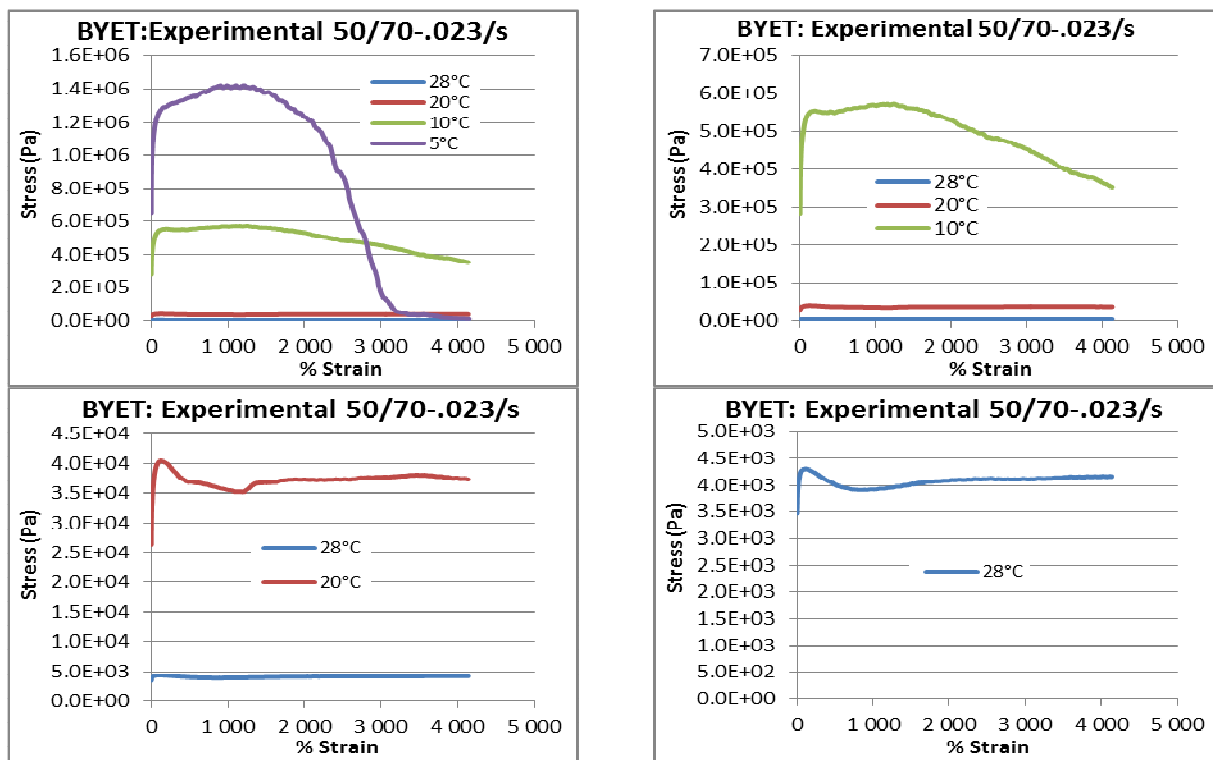


Figure 6. BYET test results for Experimental 50/70 penetration grade binder at 0.023%/s.

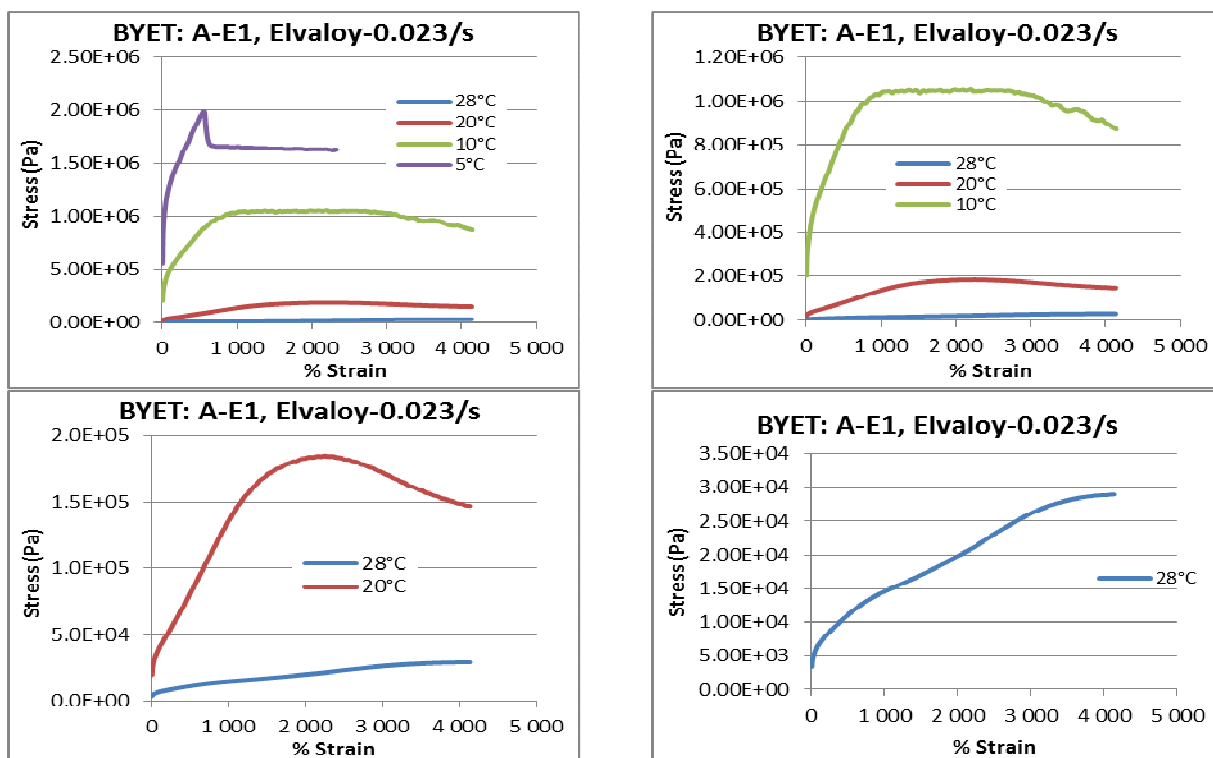


Figure 7. BYET test results for A-E1 (Elvaloy) binder at 0.023%/s.

An appraisal of the results led the authors to the following conclusions:

- The information at 5 °C contains anomalies (as illustrated in Figure 7), probably as a result of sample slippage caused by the large strains at low temperature. Therefore results at this temperature were abandoned with regards to further analysis.
- The maximum stress at 28 °C was often not attained by the end of the BYET (as illustrated in Figures 5 and 7). Similarly, the results at this temperature were also abandoned with regards to further analysis.
- At the temperatures of 10 °C and 20 °C, the graphs generated by a strain rate of 2.3%/s gave better defined maxima compared to the graphs generated at a strain rate of 1%/s.

The BYET results for 10°C and 20°C are summarised in Table 3 and 4, using the Binder Yield Energy, calculated up to γ_{tmax} (at maximum stress), and γ_{tmax} , along with the predicted fatigue ranking suggested by the results.

Table 3. Yield energy calculated from the BYET, followed by the predicted fatigue ranking.

Binder	20 °C, 1%	20 °C, 2.3%	10 °C, 1%	10 °C, 2.3%
Exp. 50/70	2.89E+04, 6	4.97E+04, 6	2.30E+06, 5	6.97E+06, 4
50/70 (2010)	1.33E+05, 5	1.34E+05, 4	3.23E+06, 4	1.27E+06, 6
50/70 (2012)	1.84E+05, 4	1.22E+05, 5	1.09E+06, 6	1.48E+06, 5
EVA-modified	1.68E+06, 1	3.92E+05, 3	4.71E+06, 3	9.68E+06, 2
Elvaloy	1.57E+06, 3	2.95E+06, 1	6.73E+06, 2	2.05E+07, 1
SBS-modified	1.61E+06, 2	2.63E+06, 2	7.01E+06, 1	8.21E+06, 3

Table 4. γ_{tmax} calculated from the BYET, followed by the predicted fatigue ranking.

Binder	20 °C, 1%	20 °C, 2.3%	10 °C, 1%	10 °C, 2.3%
Exp. 50/70	155, 6	132, 6	871, 4	1 259, 3
50/70 (2010)	681, 5	302, 4	1 177, 2	247, 6
50/70 (2012)	909, 4	256, 5	347, 6	279, 5
EVA-modified	2 227, 2	353, 3	858, 5	1 150, 4
Elvaloy	2 193, 3	2 256, 2	1 168, 3	2 200, 1
SBS-modified	2 468, 1	2 300, 1	1 545, 1	1 325, 2

3.2. Four point beam fatigue testing of asphalt mixes

The four point beam fatigue results are given in Table 5. The calculated number of repetitions to failure at 300 microstrain is reported, followed by the ranking of four point beam fatigue performance.

Table 5. Asphalt mix fatigue evaluation.

Asphalt mix binder	No. of repetitions to failure at 300 μm	Ranking
Exp. 50/70	103 177	6
50/70 (2010)	124 788	5
50/70 (2012)	144 813	4
EVA-modified	375 620	3
Elvaloy	507 650	2
SBS-modified	3 743 218	1

3.3. Correlation of binder and asphalt mix results

The BYET, using four different test conditions and using two different parameters, produce eight different sets of predicted fatigue rankings, of which not one corresponds to the four point beam fatigue results. The fatigue prediction rankings calculated with γ_{max} was poor, sometimes ranking unmodified binders above polymer-modified binders, which is contrary to four point beam results.

Technically, a correlation exercise should not be carried out when the ranking of the binder testing cannot be matched the ranking of the asphalt mix testing. However, for the sake of completeness, a limited correlation was done between the beam fatigue results and the yield energy. The results are presented in Figure 8.

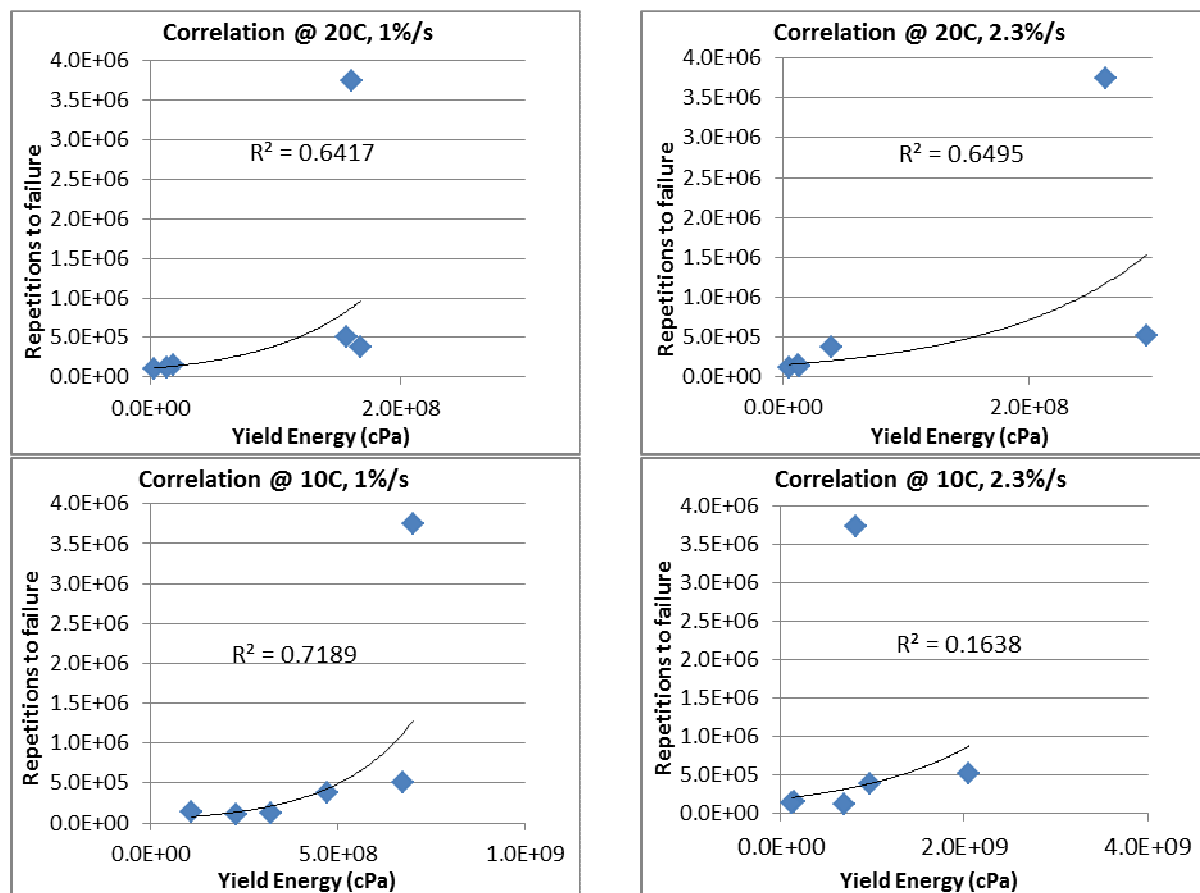


Figure 8. Correlation between beam fatigue results and yield energy.

4. Discussion and Conclusion

The BYET fatigue prediction rankings changed significantly as the temperature changed from 10°C to 20°C or as the rate of strain changed from 0.01/s to 0.023/s. The fact that slight changes in test conditions gave rise to inconsistency in the results gives rise to doubt whether the test relates well to the fundamental fatigue properties of the binder. None of the binder rankings attained from the BYET corresponded to the beam fatigue rankings. Furthermore, the double peak behaviour made it difficult to calculate BYET parameters consistently.

Based on these preliminary investigations, the BYET was not recommended for further investigation as a possible fatigue parameter for the Performance Graded binder specification in South Africa. The double peak behaviour resulted in changes in the fatigue rankings of binders with small changes in test parameters, i.e. poor repeatability. This, in turn, leads to poor correlation with asphalt mix fatigue behaviour.

Acknowledgements

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